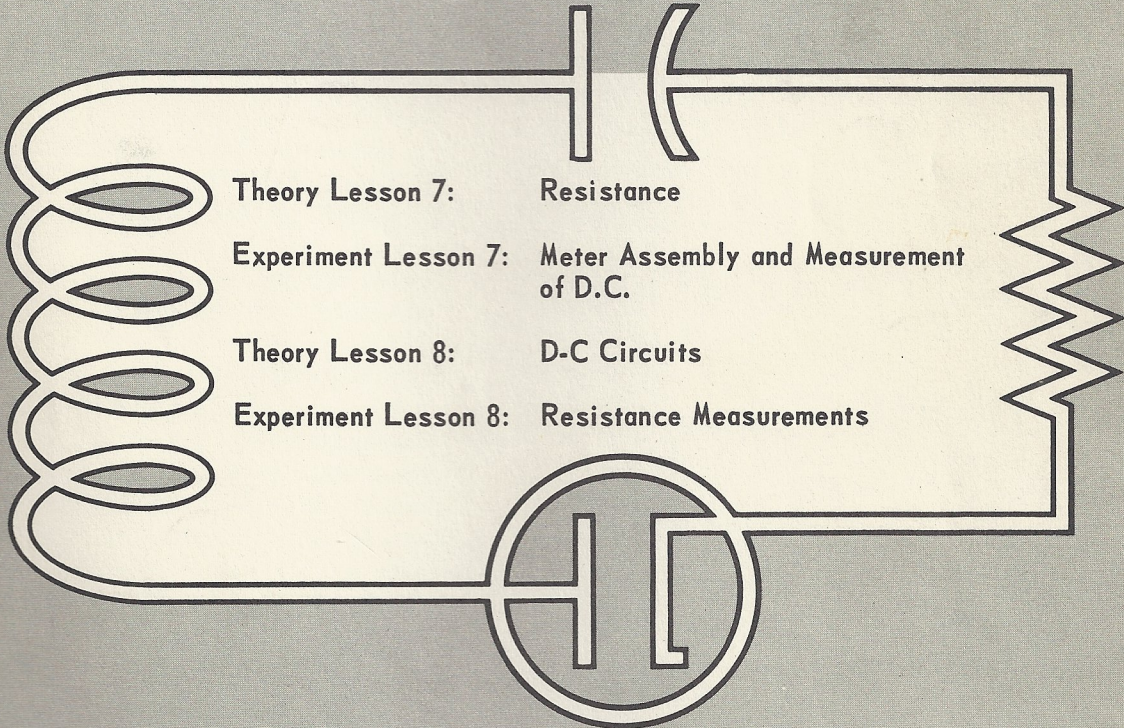


ELECTRONIC FUNDAMENTALS



Theory Lesson 7: Resistance
Experiment Lesson 7: Meter Assembly and Measurement of D.C.
Theory Lesson 8: D-C Circuits
Experiment Lesson 8: Resistance Measurements

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

New York,

N. Y.



Theory Lesson 7

INTRODUCTION

As you learned in Theory Lesson 5, resistance is the property of a circuit that opposes the flow of current in the circuit. Because all electrical circuits have some resistance, no matter how small the amount, it is important that we know what resistance does in a circuit and how we may use it to work for us.

When electric current overcomes the opposition of resistance and flows in a circuit, heat is produced. So, one way in which we use resistance is to produce heat. Electric toasters, electric heaters, and most electric stoves produce heat by having electric current flow through circuits containing resistance. For example, the spiral of wire that glows in an electric heater is nothing but a wirewound resistor.

Resistance is used in many other ways in electrical circuits. Before we study these other uses of resistors, let's learn about resistors themselves.

7-1. RESISTORS

In Theory Lesson 5, we found that

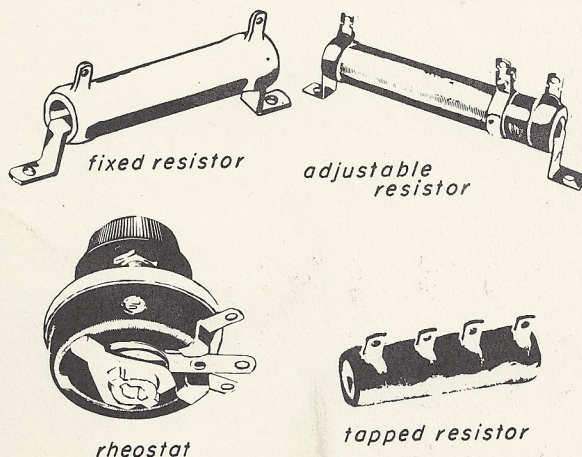


Fig. 7-1

a resistor is a part that is made so as to offer resistance to the flow of current when it is placed in an electric circuit. Resistors may be divided into two main classes: *wirewound* and *carbon composition*.

Wirewound Resistors. Wirewound resistors are made from a metal wire or a metal ribbon wound on a glass, ceramic, plastic, or fiber form. In general, wirewound resistors are used to handle high current or large amounts of power, or where great accuracy in the resistance value is important. Wirewound resistors come in several types, as shown in Fig. 7-1.

In one type, the *fixed resistor*, resistance remains the same under normal working conditions.

An *adjustable resistor* has a sliding tap or terminal that permits the resistance to be adjusted to the amount desired. Once adjusted, the resistance of such a resistor, under normal working conditions, remains the same until readjusted.

A *variable resistor*, which we usually call a *rheostat*, is one that has a sliding contact arm, normally attached to a shaft and knob. Rheostats normally have two terminals, one of which is connected to the sliding arm and the other to one end of the resistor. By turning the knob, the resistance of the rheostat may be readily set at the desired value.

A *tapped resistor* has fixed taps or terminals that divide the value of the total resistor into two or more fixed amounts. Such a resistor takes the place of two or more fixed resistors connected in series.

Carbon Composition Resistors. Carbon composition resistors are made from a composition that contains large amounts of graphite or some other form of carbon. This

composition may be formed into short lengths of rod with a wire lead wrapped around each end, as shown in Fig. 7-2a. Another way to make carbon composition resistors is to place a certain amount of the carbon composition or graphite in a short length of ceramic tubing. Lead wires are inserted in each end and the ends are then sealed as shown in Fig. 7-2b. Variable carbon composition resistors with a sliding contact are made in much the same way that wirewound variable resistors are made.

Carbon composition resistors are used in many places in radio and television where great accuracy in resistance value is unimportant, where small amounts of current flow, or where very high values of resistance are needed.

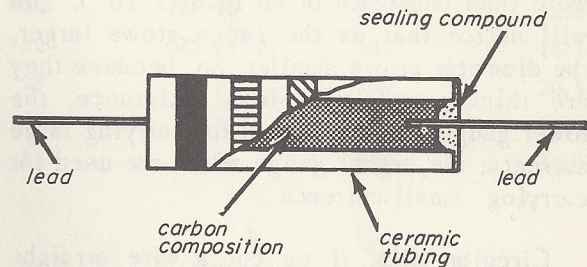
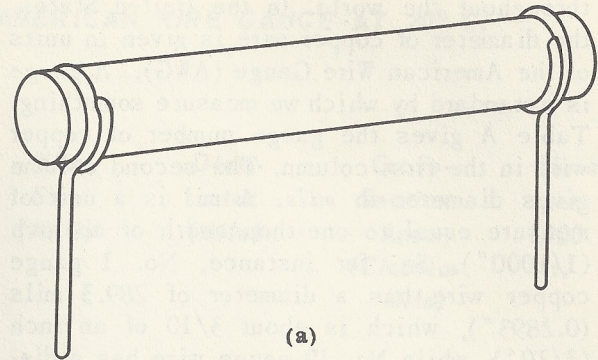
7-2. FACTORS THAT DETERMINE RESISTANCE

As you know, all substances and, therefore, all parts of an electric circuit have resistance. There are three major factors that determine resistance. These are:

1. The length of the material
2. The diameter of the material
3. The kind of material

For example, we use copper wire as a conductor of electricity in circuits. Any length of copper wire offers resistance to the flow of electric current. If we double the length of wire, using wire of the same diameter, we double the amount of resistance. If we triple the length, we have three times the resistance. So we say that the resistance of a material, such as copper wire, is in proportion to its length. Which means simply that the longer the wire is, the more resistance it has.

The next factor that determines resistance is the diameter of the substance. A fine copper wire offers more resistance than a thick copper wire. You have seen a similar condition in water hoses. For example, a hose used for sprinkling the lawn offers much more resistance to the flow of water than a hose of larger diameter used by firemen to



cutaway view of ceramic cased carbon composition resistor

(b)

Fig. 7-2

put out fires. Therefore, the flow of water through the garden hose is at a much slower rate than that through the fire hose. In much the same way, the larger the diameter of a copper wire, the less is the resistance, and the greater is the amount of current it can safely pass. From this we can see that as the diameter of the wire grows smaller, the resistance increases, and as the diameter grows larger, the resistance decreases. So we say that the resistance of a substance, such as copper wire, is in inverse proportion to the area of that substance.

When we say that two quantities are in proportion, we mean that as one quantity increases the other quantity increases, both at a fixed rate. When we say that two quantities are in inverse proportion, we mean that as one quantity increases, the other quantity decreases, both at a fixed rate.

Wire Gauges. The diameter of copper wire is measured by different standards

Resistance varies inversely with the square of the diameter

throughout the world. In the United States, the diameter of copper wire is given in units of the American Wire Gauge (AWG). A *gauge* is a standard by which we measure something. Table A gives the gauge number of copper wire in the first column. The second column gives diameter in *mils*. A mil is a unit of measure equal to one-thousandth of an inch ($1/1000''$). So, for instance, No. 1 gauge copper wire has a diameter of 289.3 mils ($0.2893''$), which is about $3/10$ of an inch ($3/10''$), while No. 10 gauge wire has a diameter of 101.9 mils, which is just a little more than one-tenth of an inch ($1/10''$). You will notice that as the gauge grows larger, the diameter grows smaller. So, because they are thicker and offer less resistance, the lower gauge wires are used for carrying large currents; the higher gauge wires are used for carrying small currents.

Circular Mils. If we cut a wire straight across, as shown in Fig. 7-3a, we can see the *cross-section* of the wire, as shown in Fig. 7-3b. The cross section of a wire is the flat area that appears when a vertical cut is made at right angles to the length of the wire. Because, the cross-sectional area is circular in all circular wires, it is sometimes more convenient to use a circular measure when we speak of this area. So, we use a unit called the *circular mil*. A *circular mil* is equal to the area of a circle that has a diameter of 1 mil ($1/1000''$). To find the cross-sectional area of a wire in circular mils, we multiply the diameter of the wire, in mils, by itself. For example, the diameter of No. 36 wire is 5 mils. Multiplying 5 times 5, we find that the area is 25 circular mils.

The third column in Table A shows that the area of No. 10 gauge wire is equal to 10,380 circular mils, while the cross-section-

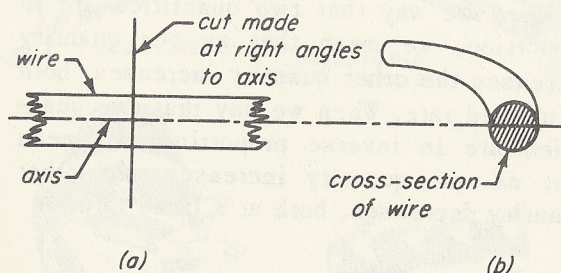


Fig. 7-3

al area of No. 20 gauge wire is equal to only 1,022 circular mils.

Specific Resistance. We compare the resistance of one material with another material by using a unit called the *circular-mil-foot*, or sometimes *mil-foot*.

A circular-mil-foot of wire is equal to a wire with a diameter of one mil, one foot long. So, to compare resistance of silver and resistance of copper, we measure the resistance of a circular-mil-foot of silver and the resistance of a circular-mil-foot of copper. We call the resistance of a circular-mil-foot of any substance the *specific resistance* of the substance. Table B shows that the specific resistance of silver is 9.88 ohms and the specific resistance of copper is 10.4 ohms. On the other hand, the specific resistance of lampblack is 18,000 – 22,000 ohms and that of graphite is 2,500 – 8,000 ohms.

Let's see how we can use the specific resistance of copper to find the total resistance of a ten-foot length of No. 36 copper wire. To find the resistance, we use this formula:

$$\text{Resistance} = \frac{\text{length (ft)} \times \text{specific resistance}}{\text{area (in cir mils)}}$$

Looking at Table B, we find that the specific resistance of copper is 10.4 (which is an approximate figure). Looking at Table A, we find that the cross-sectional area of No. 36 copper wire is 25 circular mils. So:

$$\text{Resistance} = \frac{10 \times 10.4}{25} = 4.16 \text{ ohms}$$

Temperature Versus Resistance. You will notice that the table of specific resistance gives each value, in ohms per circular-mil-foot, at 20° centigrade (68° F), which is normal room temperature. Earlier in this lesson, it was said that the three major factors that govern the resistance of a material are length, diameter, and the kind of material. Another factor that has some effect upon the resistance of a material is temperature. The resistance of most metals increases with an increase in temperature and decreases with

DOUBLE DIAMETER - RESISTANCE ÷ 4

TABLE A - BARE COPPER WIRE, AMERICAN WIRE GAUGE AT 20° C.

Wire Size (AWG)	Diam- eter (Mils)	Cross- Section Area (Circular Mils)	Ohms per 1,000 ft.	Wire Size (AWG)	Diam- eter (Mils)	Cross- Section Area (Circular Mils)	Ohms per 1,000 ft.
0000	460	211,600	0.04901	21	28.46	810	12.80
000	410	167,800	0.06180	22	25.35	642	16.14
00	364.8	133,100	0.07793	23	22.57	509	20.36
0	324.9	105,500	0.09827	24	20.10	404	25.67
				25	17.90	320.4	32.37
1	289.3	83,700	0.1239	26	15.94	254.1	40.81
2	257.6	66,400	0.1563	27	14.20	201.5	51.47
3	229.4	52,600	0.1974	28	12.64	159.8	64.90
4	204.3	41,700	0.2485	29	11.26	126.7	81.83
5	181.9	33,100	0.3133	30	10.03	100.5	103.2
6	162.0	26,250	0.3951	31	8.928	79.70	130.1
7	144.3	20,820	0.4982	32	7.950	63.21	164.1
8	128.5	16,510	0.6282	33	7.080	50.13	206.9
9	114.4	13,090	0.7921	34	6.305	39.75	260.9
10	101.9	10,380	0.9989	35	5.615	31.52	329.0
11	90.7	8,230	1.260	36	5.000	25.00	414.8
12	80.8	6,530	1.588	37	4.453	19.83	532.1
13	72.0	5,180	2.003	38	3.965	15.72	659.6
14	64.1	4,110	2.525	39	3.531	12.47	831.8
15	57.1	3,257	3.184	40	3.145	9.888	1049.0
16	50.8	2,583	4.016	41	2.75	7.5625	1370.0
17	45.3	2,048	5.064	42	2.50	6.2500	1,660.0
18	40.3	1,624	6.385	43	2.25	5.0625	2,050.0
19	35.89	1,288	8.051	44	2.00	4.0000	2,600.0
20	31.96	1,022	10.15	45	1.75	3.0625	3,390.0
				46	1.50	2.2500	4,610.0

a decrease in temperature. On the other hand, the resistance of some carbons and electrolytes decreases with a rise in temperature and increases with a drop in temperature.

We can find the resistance of a length of conducting material by using the formula:

$$R = R_o [1 \pm (a \times t)]$$

where:

R = resistance at temperature other than 20°C .

R_o = resistance at 20°C .

a = temperature coefficient per degree C.

t = degrees of temperature change

In using this formula, the product of a times t is added to 1 when the new temperature is higher than 20 degrees centigrade, and is subtracted from 1 when the new temperature is less than 20 degrees centigrade.

For example, we can find the resistance of 10 feet of No. 36 copper wire at 70°C . Table A shows that 1,000 feet of No. 36 copper wire has a resistance of 414.8 ohms; therefore 10 feet will have a resistance of 4.15 ohms. Table B shows that the temperature coefficient of copper is 0.0039. We find the resistance at 70°C :

$$\begin{aligned} R &= R_o [1 + (a \times t)] \\ &= 4.15 [1 + (0.0039 \times 50)] \\ &= 4.15 [1 + 0.195] \\ &= 4.15 \times 1.195 \\ &= 4.96 \text{ ohms} \end{aligned}$$

The resistance of the same length of wire at -10°C is found:

$$\begin{aligned} R &= R_o [1 - (a \times t)] \\ &= 4.15 [1 - (0.0039 \times 30)] \\ &= 4.15 [1 - 0.117] \\ &= 4.15 \times 0.883 \\ &= 3.66 \text{ ohms} \end{aligned}$$

Resistive Materials. Because copper and silver each have a very low specific re-

sistance, they are very seldom used as resistors, except when very low values of resistance are needed. Instead, as you know, graphite and other carbons are widely used in making resistors because each has such a high specific resistance. In making wire-wound resistors, we use metals selected for their resistivity. We call them resistive metals because they offer relatively high resistance for each circular-mil-foot. Table B shows that German silver, iron, and mercury are much more resistive than copper. In addition, certain alloys such as Advance, Eureka, Excella, Nichrome, and others are manufactured specially for making resistors. For example, one circular-mil-foot of Nichrome is over sixty times more resistive than a circular-mil-foot of copper.

7-3. CONDUCTANCE

Conductance is a circuit property that permits the flow of current. It is, therefore, a measure of the ease with which a material or circuit part permits the flow of current. It is, of course, just the opposite of resistance and is found by dividing 1 by the resistance. The answer is given in *mhos*; mho is ohm spelled backwards.

$$\text{Conductance} = \frac{1}{\text{resistance (in ohms)}} = \text{mhos}$$

For example, if a power line has a resistance of 5 ohms we find its conductance by dividing 1 by 5, which gives us 0.2 mho as the conductance:

$$\text{Conductance} = \frac{1}{5} = 0.2 \text{ mho}$$

Materials that allow a free flow of electricity are used as conductors of electricity. Copper, which is second only to silver in its ability to conduct electricity, is widely used to transmit electricity from electric power generators to our homes. As we know, when electricity overcomes resistance in a conductor, heat is produced. So, the people who supply us with electric power use copper wire because they don't want to waste electric power in producing unwanted heat. They choose copper for its *conductance*.

7-4. INSULATORS

To prevent electric currents from flowing, except where we want them to flow, we use insulators. The ideal insulator is one that permits no current to flow, no matter how high the electrical pressure is. There is no such material, because every known material permits some free electrons to pass from atom

TABLE B - TABLE OF SPECIFIC RESISTANCE AND TEMPERATURE COEFFICIENT OF CONDUCTING MATERIALS AT 20° CENTIGRADE

Conducting Material	Specific Resistance, Ohms per Cir-mil-foot	Temperature Coefficient per degree Centigrade
Advance	295	0.000018
Aluminum	17.1	0.004
Brass	40.6	0.002
Cadmium	46.0	0.0038
Carbon (lampblack)	18k-22k	0.0004*
Carbon (gas)	30k	0.0005
Carbon (graphite)	2.5k-8k	0.0003*
Climax	480-530	0.0007
Copper	10.4	0.0039
Excello	560	0.00016
German Silver	200-295	0.0004
Gold	14.7	0.0034
Iron (cast)	58.2	0.006
Lead	133	0.0042
Magnesium	27.8	0.004
Manganin	270	0.00002
Mercury	570	0.00089
Monel Metal	289	0.002
Nichrome	676	0.00017
Nickel	52.5	0.0047
Nickel Silver	166	0.00026
Phosphor Bronze	56.7	
Platinum	64.1	0.0038
Silver	9.88	0.004
Steel	79-132	0.0016-0.0042
Tin	69.7	0.0042
Tungsten	33.8	0.0045
Zinc	35.4	0.0037

*Negative temperature coefficient varies with type and source. Figures are approximate.

to atom, even though the number may be very small. However, certain materials, such as glass, mica, porcelain, and so on, permit the passage of so few electrons that, under normal working voltages, the current is so small that we can ignore it.

7-5. BREAKDOWN VOLTAGES

Of course, some materials make better insulators than others because they have fewer free electrons or can withstand the pressures of higher voltages. However, any insulating material acts as a nonconductor of electricity until the electrical pressure becomes high enough. When the voltage rises to the point that we call the *breakdown voltage*, the insulating material will act as a conductor. The reason is that as the voltage rises, the velocity, or speed of movement, of the electrons around the nucleus is so great that electrons are torn away from the atoms of the insulator, and current flows. When this happens, sparking and heat are usually produced. As a result, conducting paths may be burned through the insulator. For example, waxed paper is sometimes used as an insulator. When the voltage becomes high enough, the breakdown point of the paper is reached, and the flow of current burns small holes through the paper. As a result of the sparking and burning, the paper becomes carbonized (charred) and forms conducting paths that will then permit the flow of electric current at voltages much below the breakdown voltage. Even hard materials, such as glass, porcelain, and mica, may crack and form a conducting path.

Table C shows the breakdown voltages of some of the materials used as insulators. It shows the electrical pressure, in volts, necessary to break down these materials for each thousandth of an inch in thickness. For example, if electrical glass requires 2,000 volts pressure to break down a thickness of one-thousandth of an inch, a piece ten one-thousandths of an inch thick requires 20,000 volts pressure to cause breakdown.

7-6. PRACTICAL UNITS

As we know, values of resistance are given in ohms, while values of conductance

are expressed in mhos. However, in radio and television, resistors with values of thousands or even millions of ohms are often found. Radio and television signal voltages picked up by receiving antennas are often measured in millionths of a volt. Currents of a few thousandths of an ampere are often found in radio circuits. Even the frequency of a radio wave is expressed in thousands or millions of cycles per second. So, often in our radio and television service work, we find that ampere, volt, ohm, cycle, and many others are units either too small or too large to use conveniently. For example, conductance is very often expressed in micromhos and very seldom in mhos.

You may recall that, in Theory Lesson 1, we discussed two prefixes used in radio to simplify the expression of high frequencies. They were *kilo*, which stands for one thousand, and *mega*, which stands for one million. For example, the frequency of radio station WRCA is given as 660 kc (kilocycles), while the picture carrier frequency of TV channel 4 is 67.25 mc (megacycles). Table D shows some frequently used electrical units. For instance, note that 1,000 watts is written as 1 kilowatt. Thus, 5,000 watt-hours would appear on your electric bill as 5 kilowatt-hours. In Table D, three new prefixes are introduced: *milli*, which stands for one thousandth (1/1000), *micro*, which stands for one millionth (1/1,000,000), and *micromicro*, which stands for one millionth of one millionth (1/1,000,000,000,000).

7-7. POWERS OF TEN

You will notice that, in the last column of Table D, practical electrical units may also be expressed by using *powers of ten*. Radio servicemen, technicians, and engineers make use of this short way of writing large numbers. Take a number like 6.24 quintillion, which is written like this: 6,240,000,000,000,000,000. (You may remember from Theory Lesson 5 that this is the number of electrons in one coulomb of electricity.) It is a very large number to write or to work with. Sometimes it is easier to express large numbers by using

TABLE C - DIELECTRIC STRENGTHS OF SOME INSULATING MATERIALS IN VOLTS PER MIL OF THICKNESS

<i>Insulating Material</i>	<i>Volts Per Mil of Thickness</i>
Air (sea level)	19.8 - 22.8
Amber	2,300
Asphalt	25-30
Cellulose-Acetate	250 - 1,000
Cellulose-Nitrate	300-780
Fibre	150-180
Glass, Crown	500
Glass, Electrical	2,000
Glass, Pyrex	335
Mica, Clear, India	600 - 1,500
Micallex 364	350
Nylon	305
Paper	1,250
Paraffin Oil	381
Paraffin Wax	203-305
Phenol-Formaldehyde	400-475
Phenol-Yellow	500
Porcelain, Wet Process	150
Porcelain, Dry Process	40-100
Quartz, Fused	200
Rubber, Hard	450
Shellac	900
Steatite, Low-Loss	150-315
Varnished Cloth	450-550
Vinyl Resins	400-500

powers of ten. For instance, the number of electrons in a coulomb, in powers of ten, is expressed as 6.24×10^{18} , and is read, "six point two four times ten to the eighteenth power." Calculations in radio are greatly simplified by the use of this shorthand system. The following list shows how it works:

1	=	10^0
10	=	10^1
100	=	10^2
1,000	=	10^3
10,000	=	10^4
100,000	=	10^5
1,000,000	=	10^6 , etc.

The power of ten is increased by 1 with each additional zero.

TABLE D - PRACTICAL ELECTRICAL UNITS

Unit	Abbreviation	Equivalent		Powers of Ten
milliampere	ma	$\frac{1}{1,000}$ a	or 0.001 a	10^{-3} ampere
microampere	μ a	$\frac{1}{1,000,000}$ a	or 0.000,001 a	10^{-6} ampere
micromicro-ampere	$\mu\mu$ a	$\frac{1}{1,000,000,000,000}$ a	or 0.000,000,000,001 a	10^{-12} ampere
kilovolt	KV	1,000 v		10^3 volts
millivolt	mv	$\frac{1}{1,000}$ v	or 0.001 v	10^{-3} volt
microvolt	μ v	$\frac{1}{1,000,000}$ v	or 0.000,001 v	10^{-6} volt
micromicro-volt	$\mu\mu$ v	$\frac{1}{1,000,000,000,000}$ v	or 0.000,000,000,001 v	10^{-12} volt
kilohm	k Ω	1,000 ohms		10^3 ohms
megohm	M	1,000,000 ohms		10^6 ohms
millimho		$\frac{1}{1,000}$ mho	or 0.001 mho	10^{-3} mho
micromho	μ mho	$\frac{1}{1,000,000}$ mho	or 0.000,001 mho	10^{-6} mho
kilowatt	KW	1,000 w		10^3 watts
milliwatt	mw	$\frac{1}{1,000}$ w	or 0.001 w	10^{-3} watt
microwatt	μ w	$\frac{1}{1,000,000}$ w	or 0.000,001 w	10^{-6} watt

$$\begin{aligned}
 0.1 &= 10^{-1} \\
 0.01 &= 10^{-2} \\
 0.001 &= 10^{-3} \\
 0.0001 &= 10^{-4} \\
 0.00001 &= 10^{-5} \\
 0.000001 &= 10^{-6}
 \end{aligned}$$

The negative power of ten is increased by 1 with each additional decimal place.

Naturally, it saves time and space to use powers of ten when there are several zeros in a number. It doesn't pay to write numbers like 137,776,241 or 0.6314159 in powers of ten. However, a number like 300,000,000 is simpler when written as 3×10^8 , and 0.000000000022 is easier to work with as 2.2×10^{-11} or 22×10^{-12} . When a number is written in this form it always has two parts. The first part has one or more digits (not a zero) on the left of the decimal point, and usually other digits on the right of the decimal point. The other part is a power of 10 which places the decimal point in its true position if the indicated multiplication is carried out. This method of writing numbers often simplifies the calculation and the location of the decimal point.

One of two methods may be used to write numbers in the "powers of ten" form. The first method is based on a fundamental understanding of the system, and should be used until these fundamentals are well understood. Later the second method, which is more suited for rapid computation, may be used.

The first method is as follows:

1. The tables at the bottom of page 8 and the top of page 10 should be memorized.

2. Separate the number into two parts, so that one part is in the form given in the tables. For example, 0.009 can be separated into 9×0.001 . But from the table, 0.001 is 10^{-3} . Therefore, $0.009 = 9 \times 10^{-3}$.

3. As another example: $3,700 = 3.7 \times 1,000 = 3.7 \times 10^3$.

4. As another example: given $8.34 \times 10^4 = 8.34 \times 10,000 = 83,400$.

The second method is as follows:

1. Place a decimal point at the right of the first non-zero digit. In using this rule, the first non-zero digit is to be counted from the left; thus, in 8,749, the digit 8 is the first non-zero digit.

2. Start at this decimal point and count the digits and zeros passed over in reaching the original decimal point. The result of the count is the numerical value of the power or exponent of 10. If the count is toward the right to reach the original decimal point, the exponent is positive (+). If the count is toward the left to reach the original decimal point the exponent is negative (-).

Thus, the number in powers of ten is written as the number found in the first step multiplied by 10 with the exponent found in the second step. For example, if the number is 6203.4 a new decimal point is placed after the six. Then the number of digits and zeros passed over to reach the original decimal point is found to be three. Thus the number in powers of ten form is 6.2034×10^3 . Below are some numbers and their power-of-ten equivalents:

$$\begin{aligned}
 47290 &= 4.729 \times 10^4 \\
 0.000369 &= 3.69 \times 10^{-4} \\
 334,000,000,000 &= 3.34 \times 10^{11} \\
 17,000,000 &= 1.7 \times 10^7 \\
 0.000000000012 &= 1.2 \times 10^{-11} \\
 0.00031 &= 3.1 \times 10^{-4}
 \end{aligned}$$

The last two examples may also be written as follows:

$$\begin{aligned}
 0.000000000012 &= 1.2 \times 10^{-11} = \frac{1.2}{10^{11}} \\
 0.00031 &= 3.1 \times 10^{-4} = \frac{3.1}{10^4}
 \end{aligned}$$

Note: that when a power of ten is brought up (or down) across the fraction line, the sign of the exponent must be changed; negative exponent becomes a positive exponent, and vice versa.

If a number given in powers of ten is to be written in ordinary form, the numbers should be re-copied. Then, starting at the decimal point the number of places indicated by the exponent should be counted, supplying the necessary zeros and the new decimal point put in. If the exponent is positive, the count is toward the right; if negative, the count is toward the left. This rule may be illustrated by examining the examples above in reverse order.

When we use powers of ten, multiplication and division of large numbers become much easier. The rules are simple:

1. When multiplying, add exponents.
2. When dividing, subtract exponents.

Let us see now how this can be used to simplify the calculation of $5,790,000 \times 0.000283$. By the procedure of the two steps, stated above, this can be written as $5.79 \times 10^6 \times 2.83 \times 10^{-4}$. By combining the exponents of 10, this is written as $5.79 \times 2.83 \times 10^2$. (In multiplication, the exponents are added; $10^{-4} \times 10^6 = 10^2$.) Then since 5.79 is almost 6, and 2.83 is almost 3, the product of these two numbers is about 18. Actual multiplication shows it to be 16.39. Hence, $5.79 \times 2.83 \times 10^2 = 16.39 \times 10^2 = 1639$. The answer can be left in this form, or written as 1.639×10^3 .

For convenience in calculation, the form of the number can be changed as desired. For example, 1.234×10^3 can be written as 12.34×10^2 . The rule is: If the first part of the number is increased by 10 (decimal point moved one place to the right), the exponent of 10 is decreased by one. Or if the exponent of 10 is increased by one, the number is decreased by 10 (decimal point moved one place to the left).

Example 1:

$$\begin{aligned} 1,234 &= 1.234 \times 10^3 = 12.34 \times 10^2 \\ &= 0.1234 \times 10^4 = 12,340 \times 10^{-1} \end{aligned}$$

Example 2:

$$\begin{aligned} 0.00314 &= 3.14 \times 10^{-3} = 31.4 \times 10^{-4} \\ &= 0.314 \times 10^{-2} \end{aligned}$$

Example 3:

$$\frac{36 \times 10^5}{2 \times 10^2} = \frac{360 \times 10^4}{2 \times 10^2} = 180 \times 10^2 = 18 \times 10^3$$

Example 4:

$$\frac{36 \times 10^5}{2 \times 10^{-2}} = \frac{36 \times 10^5 \times 10^2}{2} = 18 \times 10^7$$

Example 5:

$$\begin{aligned} &12,000 \times 11,000,000 \\ &12,000 = 1.2 \times 10^4 \\ &11,000,000 = 1.1 \times 10^7 \\ &1.2 \times 10^4 \times 1.1 \times 10^7 \\ &= 1.2 \times 1.1 \times 10^{4+7} \\ &= 1.32 \times 10^{11} \\ &= 132,000,000,000 \end{aligned}$$

Example 6:

$$\begin{aligned} &0.0003 \times 0.000009 \\ &0.0003 = 3 \times 10^{-4} \\ &0.000009 = 9 \times 10^{-6} \\ &3 \times 10^{-4} \times 9 \times 10^{-6} \\ &= 3 \times 9 \times 10^{(-4) + (-6)} \\ &= 27 \times 10^{-10} \\ &= 0.0000000027 \end{aligned}$$

Example 7:

$$\begin{aligned} &700,000 \times 0.0004 \\ &700,000 = 7 \times 10^5 \\ &0.0004 = 4 \times 10^{-4} \\ &7 \times 10^5 \times 4 \times 10^{-4} \\ &= 7 \times 4 \times 10^{5-4} \\ &= 28 \times 10^1 \\ &= 28 \times 10 = 280 \end{aligned}$$

Note that when we add plus 5 and minus 4, we get plus 1.

When dividing with powers of ten, sub-

tract the exponent of the divisor from the exponent of the dividend (the amount to be divided). For example:

Example 8:

$$\begin{aligned} 360,000 &\div 40 \\ 360,000 &= 3.6 \times 10^5 \\ &= 36 \times 10^4 \\ 40 &= 4 \times 10^1 \\ 36 \times 10^4 &\div 4 \times 10^1 \\ &= (36 \div 4) \times 10^{4-1} \\ &= 9 \times 10^3 \\ &= 9,000 \end{aligned}$$

Note that we used 36×10^4 instead of 3.6×10^5 to make the final division easier.

Example 9:

$$\begin{aligned} 220,000 \times 45,000 \times 3,000 \\ &= 2.2 \times 10^5 \times 4.5 \times 10^4 \times 3 \times 10^3 \\ &= 2.2 \times 4.5 \times 3 \times 10^5 \times 10^4 \times 10^3 \\ &= 29.7 \times 10^{12} \end{aligned}$$

Example 10:

$$\begin{aligned} 500,000 \times 0.00006 \times 0.002 \times 40,000 \\ &= 5 \times 10^5 \times 6 \times 10^{-5} \times 2 \times 10^{-3} \times 4 \times 10^4 \\ &= 5 \times 6 \times 2 \times 4 \times 10^5 \times 10^{-5} \times 10^{-3} \times 10^4 \\ &= 240 \times 10^1 = 2400 \end{aligned}$$

Example 11:

$$\begin{aligned} &\frac{12,000 \times 8,000 \times 0.005}{40,000} \\ &= \frac{1.2 \times 10^4 \times 8 \times 10^3 \times 5 \times 10^{-3}}{4 \times 10^4} \\ &= \frac{48 \times 10^4}{4 \times 10^4} = \frac{48}{4} = 12 \end{aligned}$$

Example 12:

$$\begin{aligned} 0.0012 \times 5,000 \times 0.00004 \div 0.02 \times 0.04 \times 5 \\ &= 12 \times 10^{-4} \times 5 \times 10^3 \times 4 \times 10^{-5} \div 2 \times 10^{-2} \\ &\quad \times 4 \times 10^{-2} \times 5 \times 10^2 \\ &= 12 \times 5 \times 4 \times 10^{-4} \times 10^3 \times 10^{-5} \\ &\quad \div 2 \times 4 \times 5 \times 10^{-2} \times 10^{-2} \times 5 \times 10^2 \\ &= 240 \times 10^{-6} \div 40 \times 10^{-2} \\ &= \frac{240 \times 10^{-6}}{40 \times 10^{-2}} = \frac{240 \times 10^{-6}}{40 \times 10^{-2}} \\ &= 6 \times 10^{-4} = 0.0006 \end{aligned}$$

Example 13:

$$\begin{aligned} 4,180,000 \times 50,000 \times 0.005 \div 0.0055 \\ &= 4.18 \times 10^6 \times 5 \times 10^4 \times 5 \times 10^{-3} \div 5.5 \times 10^{-3} \\ &= 4.18 \times 5 \times 5 \times 10^6 \times 10^4 \times 10^{-3} \div 5.5 \times 10^{-3} \\ &= 104.5 \times 10^7 \div 5.5 \times 10^{-4} \\ &= \frac{104.5 \times 10^7}{5.5 \times 10^{-4}} \\ &= \frac{104.5 \times 10^7 \times 10^4}{5.5} = \frac{104.5}{5.5} \times 10^{11} \\ &= 1.9 \times 10^{11} \end{aligned}$$

The examples you have just seen show you how to work with powers of ten. However in order to be completely prepared to solve problems that use powers of ten, you should practice solving such problems until you have no trouble with them. Make up your own problems and solve them. Check your results by using ordinary arithmetic with powers of ten.

As you practice solving such problems you will find that it becomes easier and easier to use powers of ten. Soon you will be using powers of ten more easily than you now use the arithmetic you already know.